

ORIGINAL ARTICLE

Is the geomagnetic map imprinted in pre-emergent egg?

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Although it is well-accepted that the geomagnetic field (GMF) plays an important role in animal navigation and migration, key problems remain unanswered. To explain the puzzling ability of hatchlings to embark on unexplored migrational journeys we hypothesize that mothers who have previously navigated the trip enable their offspring by direct transfer of route information to their eggs prior to hatching. The freshly hatched animal registers the local GMF as a reference point before embarking on the journey the mother has prepared for it. This process represents a novel type of biological cycle that finesses the need to treat questions such as natal homing and route parameters separately.

Keywords

Migration, philopatry, geomagnetic imprinting, map and compass, sea turtle, lobster

History

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The problem of geomagnetic (GMF) sensitivity in animals for navigational purposes was famously parsed by Kramer (1950) into map and compass categories. A reasonable approach to the latter question, i.e., merely asking how the field is detected, is currently in progress, highlighting radical pair recombination processes stemming from excitation of cryptochrome photoreceptors in the visual pathway (Ritz et al., 2004; Rodgers and Hore, 2009). However, the second question, asking how geomagnetic maps are formed in animals (Boles and Lohmann, 2003; Lohmann et al., 2007), remains unresolved, though it is less troublesome when considering mature animals that have been exposed to magnetic fields in areas removed from home. It is conceivable that GMF map storage can occur for young animals when they accompany their elders for the first time, as is the case for birds, but there is a puzzle surrounding the means by which unaided juveniles appear capable of utilizing previously unexplored portions of the GMF map (Putman et al., 2014). Apart from falling back on the ill-defined term “instinct” this phenomenon has to date been very difficult to explain. Here we propose a new answer to this question, suggesting that the mother plays a heretofore unrecognized role in conveying map information to the pre-emergent hatchling.

Lohmann and co-workers (2008) divided this problem into two parts, suggesting that for salmon and sea turtles, natal return is in part made possible by local GMF imprinting upon hatching. They argue that this initial imprint is then augmented for subsequent round-trip journeys by means of geographically associated magnetic, olfactory and visual factors. Although the first part of this approach appears

reasonable the latter component, that involving the initial solomigration, remains unclear.

There is an alternative possible explanation as to how magnetic mapping occurs in newly hatched juveniles, one that can be thought of as a one-step version of Lohmann's concept. Noting that much of the evidence for natal return is found in egg-laying genera, e.g. bird, lobster, turtle, etc. (Creaser and Travis, 1950; Gould, 1982; Hueter et al., 2005; Putman et al., 2013; Rooker et al., 2008; Salmon and Lohmann, 1989) we propose that survival strategy in oviparous animals can include pre-hatching transfer of information, notably including GMF inclination mapping, as well as the various environmental parameters that help define the route, directly from parent to egg. Clearly this would require a transfer of rather high levels of data, sufficiently complex to be regarded as counter intuitive. There already is evidence for simpler mother–egg interactions, for example, cytosolic transfers of mRNA (Mousseau and Fox, 1998). Additionally, in response to environmental need, some passerine birds are able to enhance competitive behavior in their offspring by increasing androgen levels prior to hatching (Duckworth et al., 2015). Further, unique calls by fairy wren mothers are directed to their eggs for future use by hatchlings in competing against intruders for food (Colombelli-Négrel et al., 2012). This raises the question: if auditory and hormonal information can be transmitted to eggs prior to hatching, why not chemical or magnetic?

In our suggested scenario map routing is stored by the mother not only for use from one journey to the next, but is also somehow conveyed to the developing egg. Viewed in the large this results in an interesting new type of biological expression, allowing one to think of the utilization of the proposed GMF-related mother–egg–mother–egg-cycle as a single process spanning many generations. And, because the

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overall interaction can be regarded as occurring only between the GMF and this one larger system, the door is left open to accommodate gradual changes in the long-term geomagnetic environment, to say nothing about the remainder of those non-magnetic environmental inputs that comprise information about migration routes.

This concept lends itself to definitive experimental investigation. For example, one could attempt to determine whether offsprings' initial journeys are affected by mothers whose routes are artificially changed, or equally interesting, expose unhatched eggs at various stages of development to different magnetic signatures to test for differences in post hatching routes. There already is some indication that turtle eggs are sensitive to the fields in which they develop. Experiments by Fuxjager et al. (2015) reveal that the "magnetic environment present during the early development can influence subsequent magnetic orientation behavior of neonates."

Less obvious is the means whereby information relating to the GMF can be transferred from mother to egg. We can imagine two pathways for such a possibility, one chemical, the second magnetic, both requiring the mother to have available previously stored *integrated* information related to its round trip journey.

The most likely of the two explanatory mechanisms is that which would extend the usefulness of the magnetochemical response originating in the retina (Rodgers and Hore, 2009) that has been widely invoked to explain compass sensitivity. We suggest that the corresponding integrated data, covering the mother's entire journey, which is stored in the memory for repeat round trips, is also available for the developing egg. Presumably this would take the form of the neurochemical changes occasioned by the radical pair processes that provide the mother with a coherent geographically sequenced record of the corresponding geomagnetic inclination values.

A second, but decidedly more speculative path for information transfer might be found in reports (Alberto et al., 2008; Comisso et al., 2006; Pazur, 2004; Zhadin et al., 1998) claiming that extremely low frequency (ELF) magnetic fields, at vanishingly weak intensities on the order of 40 nT, are capable of affecting the conductivity of polar amino acid in aqueous solution. If these measurements stand, and are applicable to neurological expression then serious consideration must be given to the possibility that very weak magnetic fields play a heretofore unrecognized role in brain function. In this latter case the information content concerning the mother's route would be delivered in the form of ultra-small magnetic fields that are endogenously generated by the mother. However, these fields would only serve as the carriers of information, not as direct representations of the local and route geomagnetic fields. This idea presupposes that one of the factors within the developing egg is the local electromagnetic field.

Worth noting are the wider ramifications of this idea. For one thing the usual distinction between map and compass becomes less clear. Birthplace may be imprinted as a compass response, but the enabling route is mapped by the mother for the next generation. Thus, there emerges an integrated whole where parent, egg and hatchling can be regarded as components of a single biological system that employs both

map and compass in the course of its overall life cycle. When viewed in this manner, as a single unified process, the geomagnetic imprinting of the newly hatched animal becomes a reference point for natal return that helps fix the overall cycle that is already in place because of the mother's contribution.

Declaration of interest

The author reports no conflicts of interest. The author alone is responsible for the content and writing of this article.

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